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# Control of Microorganisms of Public Health Concern in Water

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## ABSTRACT

The concept of microbial barriers in water supply and wastewater treatment involves a variety of processes other than disinfection. Many of these treatment processes have evolved from the enhancement of some factors associated with natural self-purification (sedimentation, aeration, nutrient limitations, water pH, etc.). Utilizing the multiple barrier concept in treatment of wastes before discharge to receiving waters and the further refinement possible by natural self-purification processes in the stream are beneficial in optimizing the quality of this raw water resource prior to further processing into drinking water supplies. A flow diagram based on typical percent removals in various treatment processes illustrates how water contaminated with fecal wastes can be improved in quality to protect downstream users from microbial hazards.

## INTRODUCTION

A microbial barrier approach is used to manage water quality for downstream uses that involve public health concerns with water contact recreation, water supply, and shellfish growing areas. Surface waters are often laden with a variety of domestic and industrial wastes and stormwater runoff that carry fecal wastes from man and other animals. Groundwater may also become contaminated by seepages of landfill leachates, injection of poor quality waste effluents and movement of polluted waters from waste lagoons through ground faults into the aquifer below. All of these sources of fecal pollution bring a variety of pathogenic bacteria, viruses, fungi and multicellular parasites into the water resource. Controlling these organisms of public health concern requires careful management of a series of barriers, including natural and human engineered, in waste water and water supply treatment.

## NATURAL SELF PURIFICATION

The first and most fragile barrier to organisms of public health concern is natural self-purification common to all aquatic environments. Every stream, lake, estuary and water aquifer has some limited capacity to self-purify with surface waters generally having greater capacity than groundwater. Purification mechanisms involve:

- sedimentation
- nutrient limitations
- competitive microbial flora
- predators
- aeration
- sunlight exposure
- water temperature
- water pH
- travel time downstream or holding time if the water is impounded or part of an underground aquifer

As an example of these effects, quiescent waters aid in rapid settling of particles which entrap bacteria in the sedimentation process and remove many microorganisms from the water column. Study of the microbial populations in bottom sediments has revealed approximately 100- to 1000-fold more viable fecal coliform bacteria in the sediment water interface than in overlying waters. Salmonellae were also isolated with far greater frequency from these bottom sediments than directly from the overlying water.[1,2]

The importance of bacterial predators cannot be overlooked as a force that limits the population level of bacteria in receiving waters. The protozoan *Paramecium* is dependent on bacteria as a food source and has been found to die out rapidly in bacterial-free wastewater; however, when both bacteria and protozoa are present, the protozoan feeder population increases as the bacterial population declines.[3] *Colpidium* is another protozoan that has been found to appreciably reduce heterotrophic bacterial populations to a coexistence level of $1 \times 10^6$ cells per ml.[4] As for coliform bacteria specifically, *Tetrahymena* has been shown to hold *Klebsiella pneumoniae* to coexistence levels[5] and *Colopoda steninii* limited *E. coli* to a steady state level of $2 \times 10^3$ cells per ml.[6] While these limiting densities for bacteria by predators do not approach the desired reductions needed for acceptable water quality, they are important contributions, nevertheless.

Sunlight is an important environmental biocide capable of inactivating coliform bacteria to depths of 4 m (13 ft) in very low turbidity seawater and open water conditions.[7,8] Near-UV and visible light radiation of sunlight may be responsible for rapid inactivation of fecal coliforms in marine waters.[9, 10] Even poliovirus has been reported to be inactivated by sunlight.[11] However, the effectiveness of this natural disinfectant is subject to considerable variation due to the modifying influences of sunlight hours, and intensity, water turbidity, color, air pollution and organisms to be controlled. Sunlight alone has been found to be ineffective against the cysts, eggs, larvae of a variety of waterborne animal agents that are of serious concerns in many areas of the world including *Entamoeba, Giardia, Balantidium, Ascaris, Trichuris, Enterobius, Taenia, Clonorchis, Parazoniums, Schistasoma, Ancylostoma* and *Strongyloides*.

All things considered, the total impact of various environmental factors results in a microbial barrier to many organisms of public health significance, given sufficient time for interaction before the water is used downstream. A study of coliform reductions observed in

*Key words: microbial barriers, wastewater treatment, water supply treatment, natural self-purification, public health concern, coliform bacteria*

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**Table 1. Effectiveness of Natural Self Purification on Coliform Reduction in Surface Waters[12]**

| Ambient Waters | Season | T90 (Hours) | Reference |
|---|---|---|---|
| Ohio River | Summer | 47 | Streeter[13] |
| | Winter | 51 | |
| Missouri River | Winter | 115 | Kittrell et al[14] |
| Tennessee River | Summer | 53 | Kittrell et al[14] |
| Sacramento River | Summer | 32 | Kittrell et al[14] |
| Cumberland River | Summer | 10 | Kittrell et al[14] |
| Glatt River | Summer | 2.1 | Waser et al[15] |

*Flow time to achieve 90% reduction
Data revised from Wuhrmann

various rivers (Table 1) reveals wide differences in the number of hours of contact needed in travel time downstream to achieve a 90% kill. These variations from river to river are in response to the rate of water flow downstream and the amount of pollution load to be assimilated.

## WASTEWATER TREATMENT

Unfortunately, the growth of human activities along the rivers and lakes of the world has become so intense that often there is not a sufficient recovery zone downstream for natural barriers to be effective. Furthermore, the magnitude and complexity of wastes discharged to receiving waters overcome the capacity for self-purification or negate some of the critical natural factors.[16] Because of the unpredictability of this natural self-purification barrier, a controlled treatment approach is essential.

Controlling pollution must start with the collection of all wastes for treatment at specified sites. Diversion of all residential wastes to a pipe network for collective disposal has been found to be an effective means of reducing fecal contamination in numerous individual water supplies and recreational lakes. In many developing nations, this action is one of the first steps towards improved community public health.

Upon collecting raw sewages, the next objective is application of a variety of carefully controlled treatment processes to improve the effluent quality. Engineered treatment is the controlled utilization of various physical, chemical or biological factors to recondition contaminated water by holding it in a compartment for a specified time to maximize removal, sequestering or conversion of undesirable impurities. Many of these treatment processes such as settling, aeration and biological activity have their origins in the natural self-purification phenomenon. The difference lies in controlling the event through engineering to optimize for the rapid removal of contaminants and permit treatment of greater waste loadings to produce higher quality effluents.

Primary treatment consists of holding the watewater in a basin for a few hours to permit rapid settling of suspended solids. This simple treatment process can result in a general reduction of bacteria in raw sewage by 5 to 50%. However, coliform multiplication may occur during a one hour settling time in warm weather. Moreover, sedimentation in an Imhoff tank for two hours brings little or no virus reduction. The net result is that primary treatment does not provide consistent reductions of any great magnitude for organisms of public health concern. Attempts to obtain better control through disinfection of primary effluents generally yield erratic results because of high disinfectant demand due to excessive soluble organics in the partially treated wastes. More effective treatment of sewage to remove organics and microorganisms can be achieved through additional treatment of the primary effluent by a variety of biological processes (trickling filter, rotating biological contactors, activated sludge, anaerobic digestion and waste stabilization) that are commonly defined as secondary treatment methods.[17]

Frequently, the first stage of treatment beyond the removal of solids involves a trickling filter that consists of a bed of materials 1-3 m (3-10 ft) deep that supplies a large surface area for biological colonization. The trickling flow of primary settled sewage through the bed of gravel, stone, cinders or slag brings intimate contact between the primary sewage effluent and organisms established in a biological film on the filter media. Nutrients in the wastewater are adsorbed by the biofilm in the process and are used by the associated microbial community. As a result, nutrients are removed and organisms are entrapped from the wastewater effluent. After passage through a trickling filter, coliform bacterial densities decline by 82 to 97%, *Salmonella paratyphi* B by 84 to 99%, *Mycobacterium tuberculosis* by 66%, enteric viruses by 24 to 60%, tapeworm ova by 18 to 70% and cysts of *Endamoeba histolytica* by 88 to 99%.[17]

The activated sludge process is another approach to improving wastewater treatment. In this process, forced aeration of the primary effluent in a basin of 3-4.6 m (10-15 ft) depth is performed for 1.5 to 6 hours or more. During this time, aeration and activity of the microbial flora in the sludge breaks down the organic matter. Bacterial predators may be a prime factor in the bacterial reductions achieved with the densities and types of protozoans present reflecting the treatment efficiency. While there are many species of bacteria, fungi and yeast in the activated sludge, the floc-forming organisms in the recycling liquor accomplish most of the organic degradation.[17]

The rotating biological contactor process has been a recent technology development for wastewater treatment. In this process, which combines the concepts of trickling filters and activated sludges, a series of closely spaced circular plastic disks slowly rotate, partially submerged in a basin of wastewater. Biological growths form on the surfaces of the disks and the rotation alternately brings contact between the biomass and organic material in the wastewater and the atmosphere for contact with oxygen. The shearing forces created by rotation keep sloughed solids in suspension so they can be carried from this process to a clarifier and also provides a residual biomass for continued activity.[18]

Anaerobic digestion is widely used to stabilize the concentrated organic solids removed from primary settling tanks, biological filters and activated sludge plants. The waste is mixed with a sludge liquor that contains large densities of highly specialized bacteria and the biological action takes place in a process basin under anaerobic conditions. This approach provides degradation of a variety of more persistent organics into carbon dioxide and methane gases. Anaerobic digestion does not inactivate significant numbers of ova from various intestinal parasites. In fact, viable eggs have been recovered following digestion for as long as 3 to 6 months. Reductions of bacterial pathogens are somewhat variable, with removal of *S. typhi* ranging from 25 to 92.4%, and 69 to 90% for *M. tuberculosis*.[17]

Waste stabilization ponds can be an effective and economical sewage treatment, provided sufficient land is available to build holding ponds that permit 3 to 4 weeks retention of wastes before discharging to receiving waters. The basic mechanisms of stabilization pond waste treatment are those found in natural self-purification, with emphasis on oxidation to achieve substantial degradation of wastes and significant reduction in organisms of public health concern. Essential oxygen for this aerobic process is supplied by algal photosynthesis and sometimes is supplemented with forced aeration. Total coliform, fecal coliform, fecal streptococcus and *Salmonella* concentrations are generally reduced by 70 to 99.9%. Reduction of virus may range from 68 to 92%, if holding time in the pond exceeds 20 days. *Schistosoma* (the blood fluke flatworms) and other parasites that go through a motile aquatic stage persist for some time under favorable conditions.[17]

Individual sewage disposal systems (septic tanks) are used in urban areas located beyond the sewage collecting network of large metropolitan communities. Wastewater from the home flows into the septic tank where bacteria in the developing sludge degrade the organic matter, and the resulting effluent is periodically displaced to a subsurface gravel or sand-filled seepage pit or drainage field for diffusion into the surrounding soil. With careful control of the type and magnitude of kitchen wastes entering via the sink waste disposal, these small individual systems can be very effective in reducing the microbial population of raw domestic sewage. Unfortunately, septic

**Table 2. Effect of Sewage Treatment Processes on Indicator and Pathogenic Microbial Populations in Raw Sewage[17]**

| Type of Sewage Treatment | Percent Removal for Various Organisms |
|---|---|
| Primary | 5-50 |
| Septic Tanks | 25-75 |
| Trickling Filters | 18-99 |
| Activated Sludge | 25-99 |
| Anaerobic Digestion | 25-92 |
| Waste Stabilization Ponds | 60-99 |
| Tertiary (Flocculation, Sand Filtration) etc. | 93-99.99 |

tank systems are often poorly constructed, receive little maintenance or are overloaded by the householder so that treatment quickly becomes ineffective. Many septic tanks contain enteroviruses and in one instance the septic tank effluent still contained viable polioviruses six months after a child from the home contracted poliomyelitis.[19]

Wastewater treatment processes reduce the microbial content of raw sewage (Table 2). Just how much reduction will be accomplished is governed by a number of factors. Even under proper operating conditions, treated effluents still contain a portion of each type of microorganism originally present in the raw sewage. For this reason, disinfection is often mandatory to further protect downstream recreational uses of the receiving waters. Additional treatment is essential where wastewater effluent quality impacts adversely on receiving waters that are used for shellfish culture, or where direct reuse of wastewater effluent is planned to supplement the available water supply in water scarce areas. Tertiary treatment processes for secondary wastewater effluents that may consist of chemical flocculation and sedimentation, lime addition, activated carbon filtration and reverse osmosis can be used in various treatment train configurations to achieve the water quality desired for a specific reuse.

## WATER SUPPLY SOURCES

Increasing populations have placed ever greater burdens on water supplies both in terms of quantity demands and contamination potential from increased human activity over watersheds and chemical waste injections into groundwater, forcing use of less desirable supplemental raw sources that stress existing treatment effectiveness. Wastewater treatment plants, feedlots, stormwater runoff, and a host of other activities often discharge to a water course that may be the source water for a public supply. Even the most "pristine" watershed can be potentially contaminated by animals with human pathogens.

Groundwaters derived from deep aquifers are generally of good bacteriological quality because percolation of water through the soil results in the removal of much microbial pollution. As larger land areas are used to accommodate increasing populations and industrial growth, there is an increased risk of polluting high quality groundwater. Contaminants may enter the groundwater by:

- direct injection through wells
- percolation of liquids sprayed over the land
- leaking or broken sewer lines
- seepage from waste lagoons
- infiltration of polluted surface streams
- inter-aquifer leakage
- irrigation return waters
- leachates from landfills
- septic tank effluents
- upwelling of salt water

To provide greater protection of raw water sources for water supply, wastes must be treated properly to minimize pathogen relecses. Steady progress is being made nationwide to build more wastewater treatment facilities and to upgrade existing sewage treatment plants. Most important, treated wastewaters should be disinfected, unless it can be demonstrated on a case-by-case basis that there will be no adverse environmental effects. Variance from this requirement should depend on considerations of time and distance, water temperature,

**Table 3. Changing Chlorine Application in Cincinnati Water Supply Treatment Train[20]**

| | Parameter | Raw Source | Storage Basin | Coagulation & Settled | Filtered | Finished |
|---|---|---|---|---|---|---|
| $Cl_2$ Applied before Coagulation | Flow time hrs | 0 | 48 | 52 | 52.5 | 55.5 |
| | Turbidity, NTU | 32 | 1.0 | 1.2 | 0.11 | 0.10 |
| | Total Coliforms | 9,600 | 200 | < 1 | < 1 | < 1 |
| | HPC per ml | — | — | 500 | < 1 | 5 |
| | | | | $Cl_2$ Applied (3.6 mg/L) | | |
| $Cl_2$ Applied after Coagulation | Turbidity, NTU | 14 | 0.8 | 1.1 | 0.07 | 0.06 |
| | Total Coliforms | 84,000 | 2,400 | 1,400 | <1 | <1 |
| | HPC per ml | — | — | 5,500 | 15 | <1 |
| | | | | $Cl_2$ Applied (3.3 mg/L) | | |

microbiological nature of the discharge (pathogenic bacteria, viruses, and parasitic protozoans), and the efficiency of the available water treatment barriers. Several factors justify a policy of mandatory disinfection of wastewater effluents. First, is the preventive philosophy of maximizing public health protection through a multiple treatment barrier concept. Removal of any part of this barrier simply transfers an additional burden to the public water purveyor. The second concern is that wastewater treatment often is neither precise nor reliable, with some municipal plants being unable to meet permit limitations. Third is the creation of a shrinking natural self-purification capacity of receiving waters brought on by population explosions within a drainage basin.

## WATER SUPPLY TREATMENT

Effective water supply treatment has had a major impact on the reduction of waterborne disease. Where waterborne disease outbreaks have occurred, deficiencies in treatment have been major causes of the problems, particularly filter breakthrough and inadequate or interrupted disinfection. These observations illustrate the critical necessity of maintaining the integrity of all treatment barriers. Control processes in water supply treatment capitalize on many of the factors involved in natural self-purification and optimized for wastewater treatment with the major difference being the quality of raw water for processing. Treatment process design is generally custom made to address fluctuating water quality characteristics that impact on public health. For example, good quality groundwater will require only disinfection to protect the supply from periodic bacterial contamination, while a river raw source will dictate the need for a series of different treatment processes to ensure a safe public water supply.

This multiple barrier concept in water supply treatment can be illustrated from a recent investigation to reduce trihalomethane production by changing the point of chlorine application at the Cincinnati Water Works.[20]

During routine treatment plant operation, chlorine was applied to the source water after 48 hours of open reservoir storage (Table 3). Adequate retention time of source waters is itself a beneficial first step in microbial population reductions through self-purification processes, and can be a buffer against temporary impairment of water quality from an upstream accidental spill of toxic chemicals. During this 2-day retention period, there was a 98% reduction in total coliform bacteria, and raw water turbidity (Ohio River) declined by 97% because of alum treatment in the holding basins. Application of chlorine disinfection prior to coagulation and subsequent settling of the floc was effective in creating a barrier to any further total coliform penetration of the treatment train. Turbidity NTU was not changed significantly by the coagulation and settling process since alum applied during the raw water storage period had removed much of the colloidal material.

The most important feature was the preconditioning of the process water so that rapid sand filtration was very effective in further reducing

**Table 4. Microbial Barriers: Fecal Coliform Control in Water Pollution**

| Source | Fecal Coliforms (FC) | |
|---|---|---|
| **Human fecal coliform discharges** | 1,950,000,000 FC per person/day | |
| | **Fecal Coliforms per 100 ml** | |
| **Municipal raw sewage** | 8,260,000 FC cells per 100 ml | |
| **Sewage treatment reductions** | | |
| | **Cumulative Reduction (Percent)** | **FC Surviving** |
| Primary | 50 | 4,130,000 |
| Secondary | 80 | 1,652,000 |
| Tertiary | 90 | 165,200 |
| Disinfection | 99.99 | 800 |
| **Self purification and effluent dilution 10-50%** | | 400-700 |
| **Water supply treatment** | | |
| | **Cumulative Reduction (Percent)** | **FC Surviving** |
| Raw water storage | 50 | 200-350 |
| Coagulation-sedimentation | 60 | 80-140 |
| Filtration | 99.9 | 0.8-1.4 |
| Disinfection | 99.9999 | .00008-.00014 |

turbidity. Moving the point of chlorination from the post-storage step to after coagulation and settling, resulted in an intrusion of coliforms into advanced stages of water treatment and placed increased importance on maintaining effective disinfection as the final control process. Inspection of the parallel data on heterotrophic bacterial densities revealed a persistence of this broad spectrum population into the filtration process and illustrated the more resistant nature of some of these organisms to chlorine. In either event, there was no measurable change in the bacterial quality of the finished water, but the treatment train modification did illustrate the necessity of greater dependency of an effective final disinfection to inactivate residual microbial populations that had survived earlier stages of water treatment.

## COMBINING MULTIPLE BARRIERS

Combining multiple treatment barriers provides maximum protection from a variety of waterborne pathogens that may be contributed by man and other animals. Unfortunately, surface water is constantly exposed to a wide range of natural phenomena (stormwater runoff, vegetation overgrowth, ambient water temperatures) and man-induced contaminants that cause wide fluctuations in water quality. The most intense and hazardous of these influences generally are those contributed by point source pollutants.

Minimizing the hazards to downstream water users must start with controlling point source pollution and utilizing, when possible, the buffering effects of natural self-purification so that the quality of surface water available does not create a public health problem. Because there are so many variables associated with every treatment process, it is desirable to use a series of treatment processes for wastes before discharging to receiving waters rather than place the major burden of water quality enhancement on stream self-purification or water supply treatment processes. The multiple barrier approach is illustrated by the data in Table 4.

The fecal coliform content in feces discharged by one individual over a 24-hour period has been calculated to be about 1,950,000,000 cells.[21] Raw sewage analyses from 21 communities around the country averaged 8,260,000 fecal coliforms per 100 ml.[17] The difference in magnitude of fecal coliforms found in daily fecal discharges and raw sewage relates to large volume dilution in toilet flushings, kitchen wastes and other liquid discharges to the sewer system by commercial and industrial activities. Wastewater treatment processes in series can effectively reduce the fecal coliform population so that the final effluent contains less than 0.01% of the original fecal coliform content. Effluent dilution by the receiving waters and natural self-purification contribute to the further decline in microbial load as the water travels downstream towards a public water supply intake. Processing the raw source water through a multistage water treatment train can produce a low risk potable water that may contain less than one fecal coliform in 100 liters (26.4 gal) of drinking water.

## SUMMARY

Microorganisms of public health concern in water can be controlled by treatment process technology currently available. Where outbreaks have occurred, the cause has been a demonstrated failure in wastewater or water supply treatment operation or public water distribution protection. While natural self-purification in receiving waters can be an important buffer between waste effluent discharges and water supply intakes, the fragile nature of the associated phenomena cannot be a substitution for adequate waste treatment. Essential to maximum public health safeguards is the use of a multiple barrier concept that relies on establishing protective systems between the water user and sources of potential contamination. ■

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